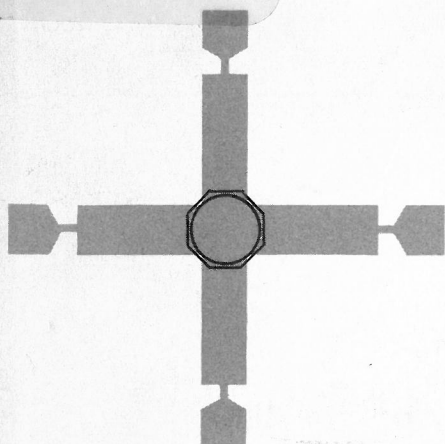


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A Review of the Mariner IV Results

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A Review of the Mariner IV Results

ORAN W. NICKS

Director, Lunar and Planetary Programs



Scientific and Technical Information Division

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PREFACE

After an interplanetary journey of seven and a half months, the spacecraft Mariner IV flew within 9847 kilometers of Mars on July 15, 1965. It returned highly useful data from the time of its launch in November 1964 until October 1965, when its great distance from Earth and its antenna orientation halted interpretation of its signal. It is at this writing known to be still functioning, however, and it may yet return more data when it approaches nearer Earth in September 1967. In terms of mission success—including transmission of the first TV imaging of the Martian surface—Mariner IV was and indeed still is an historic spacecraft.

This publication, developed from a paper presented at a COSPAR symposium in May 1966, attempts to highlight the great volume of interpretative analysis that has been elicited by Mariner IV data. It also summarizes the more important engineering advances that have derived from this flight, which has taught us invaluable technological lessons about the design, testing, and management of interplanetary probes. Finally, it reproduces, in the form of quality photoengravings, a selection of Mariner IV pictures of the Martian surface as they have been "computer-enhanced" by staff members of the Jet Propulsion Laboratory. The objective throughout has been to present a compact summary of what may well be recalled as the most remarkable interplanetary probe of the early Space Age.

ORAN W. NICKS

*Director, Lunar and Planetary Programs,
Office of Space Science and Applications*

INTRODUCTION—MARINER IV HERITAGE

Seven and a half months after its launch, the Mariner IV spacecraft flew close by Mars in July 1965. After its encounter, Mariner IV continued to return data on the interplanetary medium for $2\frac{1}{2}$ months. It is in fact still operating in space, although its vast distance from Earth, and the orientation of its antenna, have prevented the reception of meaningful data since October 1965. In 1967, however, it will pass about 29 million miles from the Earth, and we are hopeful that it will again provide a useful return of interplanetary information.

This mission has provided significant new knowledge about Mars, the environment in the solar system, and the technologies essential to interplanetary space flight. This paper presents highlights of major results from the mission.

Mariner IV belonged to a family of spacecraft, with predecessors which have successfully flown to Venus and the Moon. A basic common characteristic of Mariner and Ranger spacecraft was that they were stabilized in space with attitude referenced to celestial bodies. Both the Rangers and Mariners always pointed toward the Sun during cruise flight. Facing the solar panels directly toward the Sun provided maximum efficiency for obtaining solar electric power. This also established the reference plane for orienting two axes of the spacecraft.

Figure 1 is a comparison of Mariner II and Mariner IV showing a basic similarity in structural design, with the solar panels affording the most obvious difference in configuration. Mariner IV required more than twice the solar-panel area of the Mariner II, having a total of 70 square feet as contrasted to 27 square feet for the Mariner II. The solar vanes on the ends of the Mariner IV solar panels were also unique, designed to assist in orienting of the spacecraft toward the Sun by utilizing solar-pressure effects.

MARINER IV RESULTS

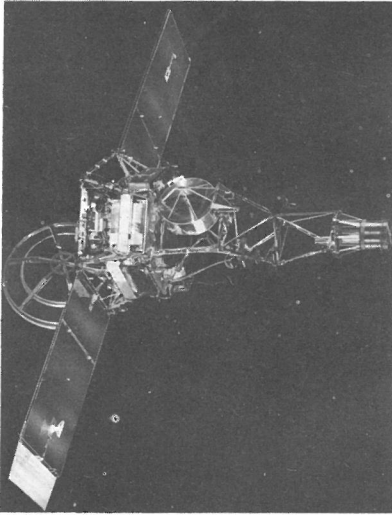
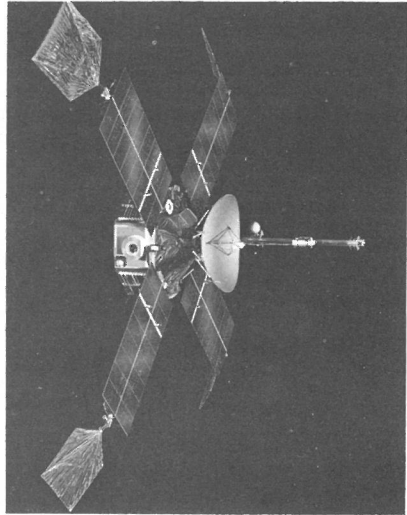
The Mariner II spacecraft contained 54 000 parts; the number increased to 138 000 parts in the Mariner IV (ref. 1). This fact serves to illustrate the evolutionary increase in technological complexity, accomplished with a growth in spacecraft weight from 440 to only 575 pounds.

The Mariner IV had to live longer in the space environment while being subjected to a widely varying range of thermal conditions. At Venus, the Sun's intensity is approximately twice that at Earth; at Mars, roughly half that at Earth.

A summary comparison of the results from Mariner II and Mariner IV (ref. 2) is shown in table I. As man's first successful spacecraft to explore other planets, these two missions contributed much valuable new information.

TABLE I.—*Mariner Results*

	Mariner II	Mariner IV
Launched	August 27, 1962	November 28, 1964
Planetary encounter	December 14, 1962	July 15, 1965
Accomplishment	First successful Venus mission	First successful Mars mission
Days of flight data	129	307
Distance at closest approach	34 833 km	9846 km
Range at encounter	57 934 800 km	216 303 650 km
Planetary findings	<ul style="list-style-type: none"> ☆ Limb darkening ☆ High surface temperature, same on dark as on light side ☆ Clouds cold—no breaks ☆ Negligible magnetic field ☆ No radiation belt detected ☆ No dust belt detected ☆ Mass of Venus accuracy 10 × 	<ul style="list-style-type: none"> ☆ Craters on Mars ☆ 4–7 millibar atmosphere ☆ No ionospheric communication problems in Mars atmosphere ☆ Negligible magnetic field ☆ No radiation belt detected ☆ No dust belt detected ☆ Mass of Mars accuracy 20 ×
Interplanetary findings	<ul style="list-style-type: none"> ☆ Little dust. 2 hits ☆ Radiation \approx 3 roentgens ☆ Character of solar plasma ☆ Character of magnetic fields 	<ul style="list-style-type: none"> ☆ 215 hits. Dust increased to 1.36 AU, then dropped off. ☆ Radiation \approx 30 roentgens ☆ Character of solar plasma ☆ Character of magnetic fields

(a) *Mariner II.*(b) *Mariner IV.*FIGURE 1.—*Mariner spacecraft.*

MARINER IV SYSTEMS AND MISSION

When the National Aeronautics and Space Administration initiated the Mariner Mars project late in 1962, it was necessary to plan in a manner that would insure a high probability for successful operation throughout a long trip in interplanetary space. A major goal of spacecraft design was that it should be fully automatic—able to complete its entire mission from launch to the end of its life without ground-based intervention, except for the trajectory-correction maneuvers and, of course, tracking and data acquisition. Another design goal was to have at least two independent means of initiating every specific function or event critical to the success of the mission (ref. 3).

The Mariner IV mission to Mars involved four major systems: the launch vehicle which placed the spacecraft into its proper transfer orbit; the spacecraft system which carried scientific equipment and which performed all programmed activities successfully at the proper time; the Deep Space Instrumentation Facility which tracked the spacecraft, transmitted necessary commands to it, and received its transmitted information; and the Space Flight Operations Facility, where trajectories were computed, and where direct control of the spacecraft was exercised, including commands to gather and store information.

The mission was conducted after some 2 years of preparation. The launching took place on November 28, 1964, at 14:22:01 G.m.t., and the space-

MARINER IV RESULTS

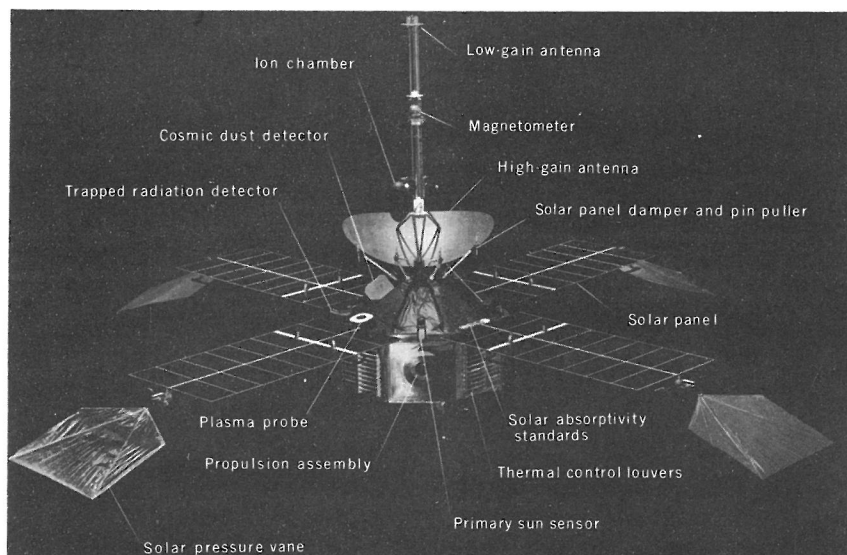


FIGURE 2.—*Mariner IV* configuration.

craft arrived at Mars on July 15, 1965, at 01:00:57 G.m.t. Tracking and data acquisition were carried out 24 hours a day throughout most of the mission (ref. 4).

The Mariner spacecraft shown in figure 2 was characterized by an octagonal compartmented body structure containing electronic components; four sets of solar panels which were folded until after the spacecraft was separated from the boost vehicle; a high-gain, elliptical, 4-foot antenna; and a mast containing an omni-directional antenna and several scientific experiments. Although a rechargeable battery was carried, virtually all spacecraft power came directly from solar panels which were oriented toward the Sun at all times during cruise flight. The power supply provided some 600 watts of raw power near the Earth; this dropped to about 300 watts near Mars owing to the greater distance from the Sun. Since about 150 watts were required for operating the spacecraft on a continuous basis, some margin existed for possible failure modes. Sun sensors and a nitrogen-gas attitude control system were used to maintain the longitudinal direction of the spacecraft toward the Sun. A tracker sensed the bright star Canopus in the southern hemisphere, allowing gas jets to position the spacecraft during cruise flight in a roll attitude.

To correct the path of the spacecraft after its separation from the launch vehicle, a small rocket motor, capable of two firings at 50 pounds of thrust, was used. With the attitude reference system provided by the Sun, the Canopus tracker, and an autopilot, it was possible to orient the spacecraft on command to a calculated heading, and then by firing this rocket for a calcu-

lated time, to correct the trajectory. More will be said about this correction maneuver and its effectiveness later.

The spacecraft contained seven scientific instruments for measurements of the interplanetary environment and characteristics of the planet Mars. A 10-watt transmitter system, with dual channels for insurance in the event of failure, transmitted data to Earth at a rate of $33\frac{1}{3}$ bits per second near Earth, and at $8\frac{1}{3}$ bits per second from greater distances. The solar vanes on the ends of the solar panels provided a degree of stability about two axes, using solar pressure (about a millionth of a pound per vane) as the restoring force. These vanes were used in this application for the first time and proved the feasibility of this technique. Thermal louvers were employed to control actively the temperatures in the electronic compartments (refs. 3 and 5 to 7).

Figure 3 illustrates the Mariner trajectory from Earth to Mars. The flight time to Mars was some 228 days, and the distance traveled in orbit to Mars was some 524 million kilometers. The figure shows relative positions of the spacecraft, the Earth, and Mars at launch, encounter, and at the time the Mariner will return near Earth in 1967.

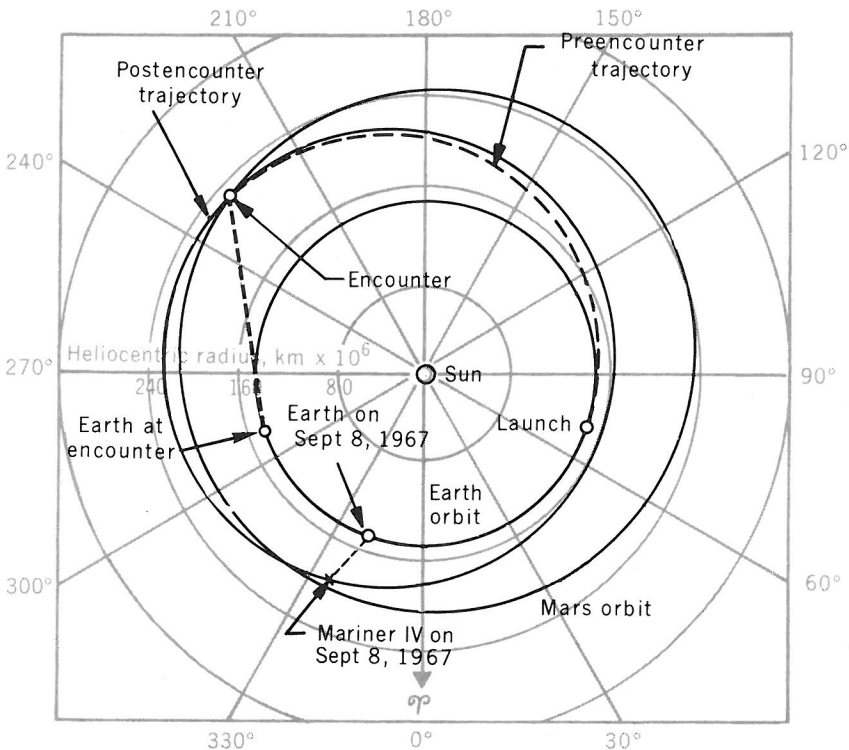


FIGURE 3.—Mariner IV trajectory.

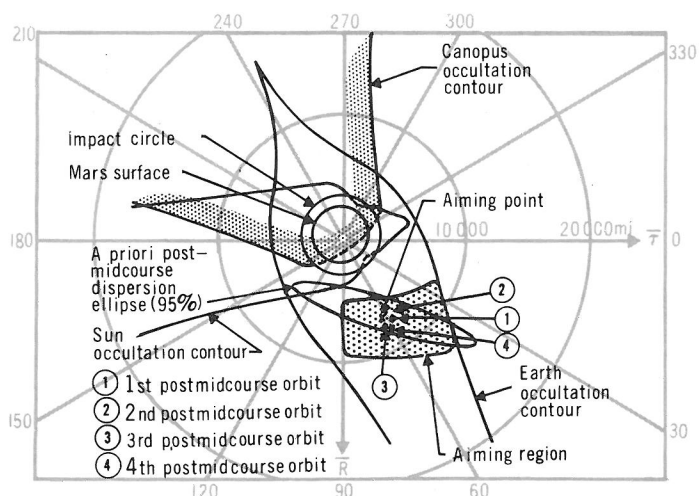
MARINER IV RESULTS

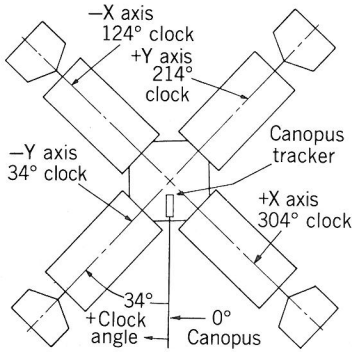
Trajectory elements have been established for the orbit of the spacecraft after encounter with Mars. They indicate an aphelion or farthest distance from the Sun of 235 331 000 kilometers, a closest approach to the Sun of 165 849 000 kilometers, and a period of 567 days. Early in 1966, the spacecraft was opposite the Earth on the other side of the Sun, and on September 8, 1967, it will approach the Earth again to a distance of about 46 946 445 kilometers (ref. 4).

Although the launch vehicle performed well in starting the Mariner spacecraft on its way, initial tracking established the fact that, with no vernier trajectory adjustment from the spacecraft motor, the Mariner would pass about 243 000 kilometers from Mars about 2 days later than it actually arrived. Accordingly, on December 5, 1964, a midcourse maneuver was executed by ground command (ref. 5). Figure 4 shows the target zone and the spacecraft approach in a plane at Mars. The actual aiming point for calculating the desired correction maneuver was selected to provide a closest approach of about 7080 kilometers (4400 statute miles) from Mars' surface. Several days of tracking after the maneuver indicated that the flight-path correction was sufficiently accurate to cause the spacecraft to come within about 2400 kilometers (1500 statute miles) of the aiming point; its closest approach at encounter was actually 9846 kilometers (6118 statute miles), near the middle of the target zone.

The correction for time of flight was also an important consideration in making the maneuver, since it allowed the camera to look at the desired part of Mars (Mars rotates once every 24 hours 37 minutes). In addition, the correction allowed the Goldstone, California, tracking facility to be in sight of the spacecraft upon arrival. Since the Goldstone station has the greatest transmitting and receiving capability of all Deep Space Network stations

FIGURE 4.—
Mariner IV
aiming zone.



FIGURE 5.—*Canopus sensor clock angle.*

and is nearest the Space Flight Operations Facility in Pasadena, it was desirable that the station be in use at the time of encounter.

Figure 4 also shows the nature of the aiming constraints. In the zone above Mars the view of the Canopus sensor would have been blocked, with the result that the sensor would have lost its reference on Canopus. The zone to the left is the region in which the spacecraft would have lost sight of the Sun and, consequently, would have lost power and an attitude control reference. The small rectangular zone beneath the planet is the area in which all the experiments were designed to perform satisfactorily, and thus it was the desired target area. It extended outward from the planet's surface from about 1600 kilometers (1000 statute miles) to about 16 000 kilometers (10 000 statute miles), and was bounded within the zone which allowed the spacecraft to disappear from view of the Earth behind the planet, that is, to be occulted. Occultation of the spacecraft caused the radio-frequency signal to be transmitted briefly through the Martian atmosphere, and analyses of change in amplitude and frequency enabled a determination of atmospheric density and its distribution with altitude above the surface of the planet.

TECHNOLOGICAL HIGHLIGHTS

As the first man-made probe to travel successfully to Mars, Mariner IV was far more than a simple technological experiment. It was, in essence, a complex instrument performing multiple scientific experiments to extend man's knowledge by making observations in the vicinity of Mars. Many technological advances were associated with different phases of the engineering evolution and technical developments of the Mariner program; however, only a small fraction of the advances are summarized in the sections which follow.

Canopus Reference System

The Canopus sensor (fig. 5) was rigidly attached to the Mariner spacecraft with a field of view of 11° along the longitudinal axis and 4° in the

MARINER IV RESULTS

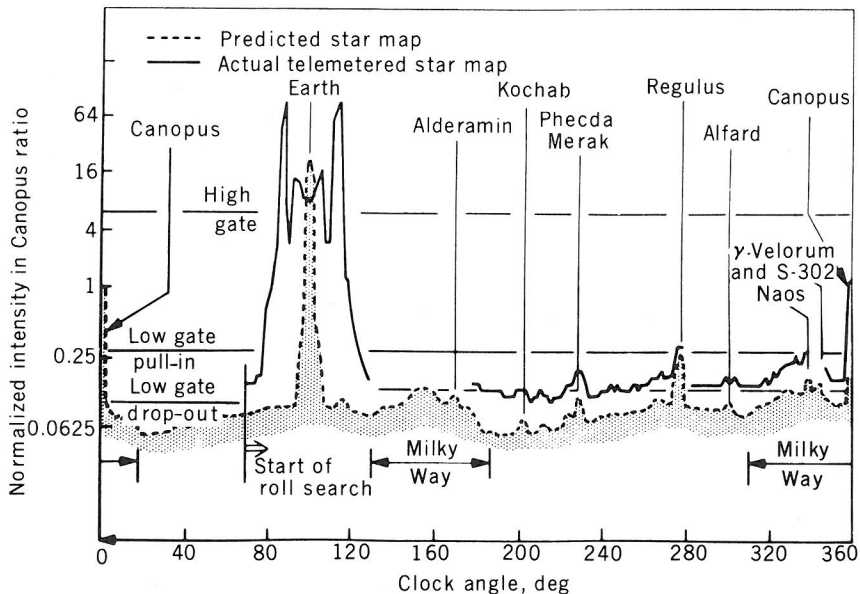


FIGURE 6.—Comparison of predicted and actual star maps at initial Canopus acquisition.

clock direction (ref. 4). This field allowed the sensor to keep Canopus in view while the longitudinal axis of the spacecraft pointed directly toward the Sun, thereby placing the solar panels in a plane normal to the Sun, and providing reference for two axes of control. The Canopus sensor provided the third axis of reference for the attitude-control system by electronically supplying signals to attitude-control gas thrusters used to position the spacecraft in roll. The Mariner Mars mission was the first successful space mission to use a star for roll reference. Earlier missions remaining near Earth or travelling in toward Venus had sighted on Earth, but during the Mariner IV flight the Earth moved across the face of the Sun, and throughout much of the flight appeared to the spacecraft as a relatively dim crescent. A bright reference source at a wide angle away from the Sun was therefore necessary. Canopus filled the requirements for such a source.

During the first 15 hours after the spacecraft was oriented toward the Sun, it was allowed to roll about the Sun axis with the Canopus tracker inactive; this permitted Mariner to move out away from the Earth's radiation belts and to allow the magnetometer to be calibrated. When the Canopus tracker was activated, the spacecraft continued to roll until the sensor saw an image within its view having an intensity from 0.04 to 8 times the expected Canopus brightness. A predicted star map for the initial acquisition period is compared with measured star intensities in figure 6. Some 423 star intensities and positions, plus those of the Milky Way, were stored in the ground-based computer for use in Canopus acquisition (refs. 3 to 5, 8 and 9).

The first object emitting light with an intensity within the range of the sensor is believed to have been the Earth, followed by Alderamin, Kochab, Phecda Merak, Regulus, Alfard, Naos, Gamma-Velorum, and finally Canopus. Acquisition of these objects corresponded reasonably with predicted sources, and after the spacecraft made one revolution of nearly 360° , the star sources and intensities were confirmed.

During the early phases of the flight, the Canopus tracker encountered some minor difficulty. Although it is not possible to be certain, it is believed that small dust particles very near the sensor may have reflected brightly and caused the sensor to lose lock momentarily with its star. This difficulty was overcome by sending a command which switched the brightness-gate circuits off after the tracker was locked on Canopus.

Several roll search cycles* occurred throughout the flight; the data from these furnished much useful information on the intensities of stellar sources in a plane nearly perpendicular to the Sun.

Solar Vane System

As the Mariner IV spacecraft was designed to remain in a fixed attitude toward the Sun during most of its journey, the solar-pressure effects on maintaining that attitude were of consequence to the requirements for attitude-control gas. A simple diagram (fig. 7) illustrates the pressures on the surface

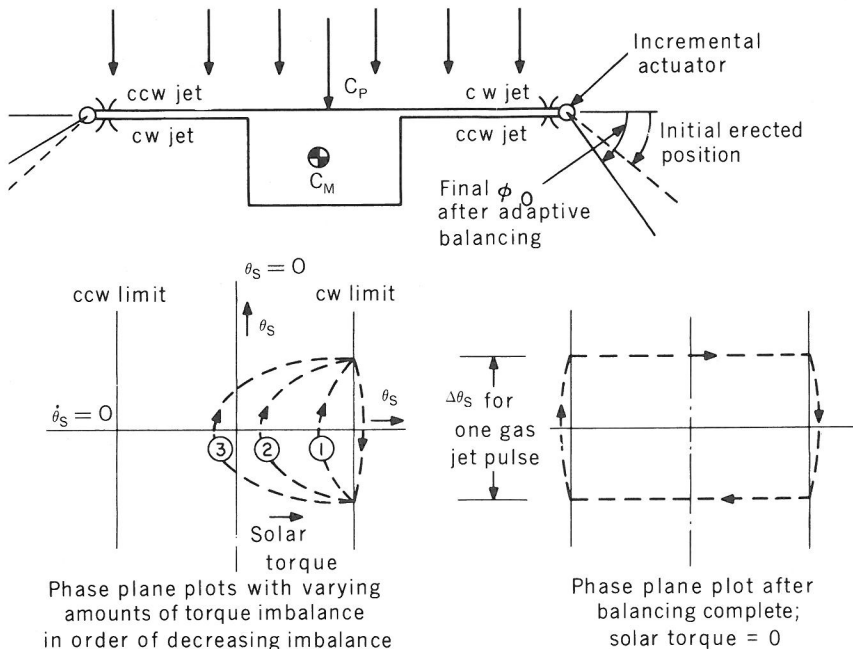


FIGURE 7.—Solar vane system.

MARINER IV RESULTS

of the spacecraft and the relative position of these pressures to the center of mass before the vanes were deployed. With the solar vanes on the ends of the panels, it can be seen that the center of pressure could be moved aft of the center of mass by sweeping back the vanes, thereby producing the stable configuration. Each vane had an area of about 7 square feet, and a total assembled weight of less than $11\frac{1}{2}$ pounds.

The force exerted by the Sun on each vane was no greater than about 1 millionth of a pound. This force was sufficient, however, to compensate for an initial unbalanced torque of up to 80 dyne-cm, thus reducing considerably the requirements for attitude-control gas (refs. 3 to 6).

The vanes were initially deployed so that the solar torque was clockwise (cw), requiring more frequent pulsing of the counter clockwise (ccw) jets than of the cw jets. An electromechanical actuator responding to a signal each time a jet was fired at the edge of the limit cycle caused a corresponding vane to move in a direction to counter the imbalance. This closed-loop system provided continuous automatic adjustment of the vanes until opposing jets were pulsing with near regular frequency, and the limit cycle characteristics of the system were modified as shown in figure 7 (ref. 5).

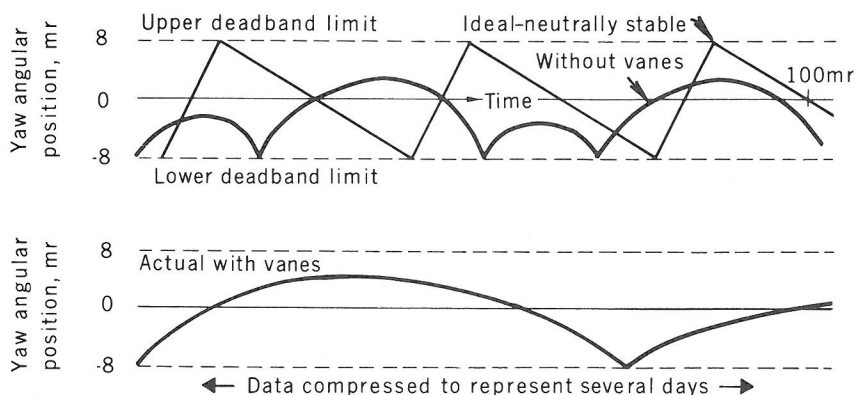


FIGURE 8.—Solar torque limit cycle performance for Mariner IV.

Figure 8 illustrates the nature of the vane effects on actual attitude variations. In this presentation, the time scale is greatly compressed; the actual time between limit-cycle jet firings varied greatly throughout the flight.

Ideally, the vanes should have been able to eliminate all radiation imbalance. Actually, data indicate that the vanes reduced the initial radiation pressure imbalance from 30 dyne-cm to an average of less than 5 dyne-cm. On 1 day, the radiation pressure imbalance acting on the yaw axis of the spacecraft was so small that a 9-hour interval occurred between successive firings of the yaw gas jets. It was not possible to balance completely the

external torque acting on the spacecraft so that the gas jets were never actuated, because the torque appeared to have a random value of ± 5 dyne-cm, and reversals of torque were observed for as short a period as 1 to 2 hours. The precise reasons for these reversals are not known, although the variations might have been caused by slight gas leaks, fluctuations in the solar wind, particle impacts, or other unaccountable disturbances. The solar-vane system on Mariner IV conclusively proved the principle of the technique, and provided engineering knowledge of value in the design of spacecraft for future interplanetary flights (refs. 9 and 10).

Telecommunications System

The telecommunications system on board Mariner IV consisted of three major elements: the radio receiver and transmitter, telemetry, and the command subsystem. The system provided Mariner its only link with Earth, broadcasting continuously at 2300 megacycles with about 10 watts of power. It transmitted the scientific measurements and data on the condition of the spacecraft and instruments. Measurements were coded digitally rather than in analog form and were imposed on the radio signal by phase-shift keyed modulation.

Figure 9 shows graphically the manner in which the carrier signal received on Earth varied as a function of time, and correlates the predicted and actual data. On December 13, 1964, the radio switched from a cavity power amplifier to the longer life, slightly more powerful traveling wave tube. Two different amplifier channels had been incorporated to provide alternate sources in the event one failed.

The rate of telemetry was slowed on January 3, 1965, from $33\frac{1}{3}$ bits per second to $8\frac{1}{3}$ bits per second for the rest of the mission. When the transmitter was commanded from the high-gain to the low-gain antenna on

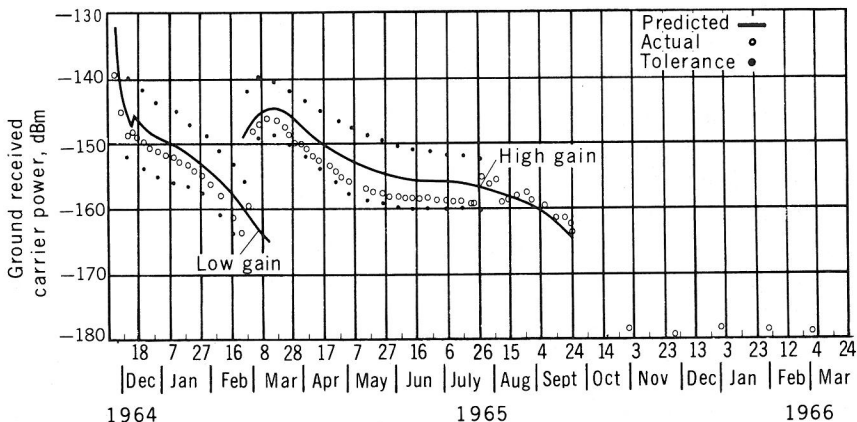


FIGURE 9.—Radio signal level at Earth for Mariner IV.

MARINER IV RESULTS

October 1, 1965, the spacecraft was 307 415 414 kilometers from Earth, and a new record had been established for long-range communications. Its signal level at that time had dropped to -163 dBm on Earth (refs. 3 to 6). Converting this value to signal power available in the receivers at the Earth gives a figure of 1×10^{-19} watt. Actual carrier signals were received at signal levels near -180 dBm after that period, as shown in the figure, but telemetry data were not interpretable.

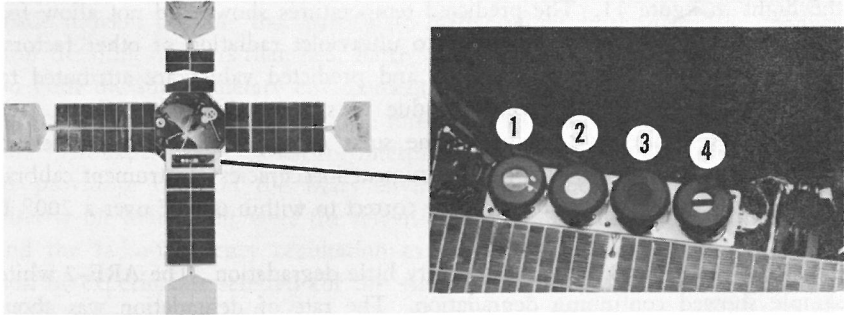
The precision and reliability of the telecommunications system was proved conclusively. All commands were received and acted upon throughout the flight. In addition, a quantitative evaluation was possible when the Mariner IV was ordered to transmit a second time the entire set of pictures taken on the flyby of Mars. The replay of the data corresponded with the initial transmission so closely that in a typical picture only 20 elements out of the 40 000 elements in the picture were different. This performance represented a truly remarkable level of accuracy for such a complex system (ref. 11).

At this time, history is still being written with regard to the communication system of Mariner. Tests are being performed with a new 210-foot parabolic antenna at Goldstone, and the Mariner radio-frequency carrier is being clearly received as it continues its orbit about the Sun.

Solar Absorptivity Standards Experiment

Because of uncertainties in the thermal design of a spacecraft required to operate for many months in space and over a range from 0.9 to 1.4 AU, many subsystem engineers wanted to provide temperature measurements for various elements of the Mariner spacecraft. Since this was impractical because of limitations on weight and telemetry, a compromise was decided upon. Four samples typical of the surfaces on the spacecraft were arranged in a simple experiment known as the solar absorptivity standards experiment. This $7\frac{1}{2}$ -month flight time to Mars, the slowly changing solar intensity, and the continuous Sun orientation of the spacecraft made the Mariner an ideal mission for this type of experiment.

The four test surfaces were selected on the basis of their temperature control use and such characteristics as ultraviolet stability, emittance, solar absorptance, and spectral sensitivity. The designations for these surfaces are shown in figure 10, along with absorptance-emissivity ratios (α/ϵ) at the beginning of flight. Polished aluminum, used extensively on the Mariner, offers the advantage of very low emissivity. Aluminum silicone paint was chosen for its gray spectral response and moderate α/ϵ ratio. Cat-a-lac black paint was chosen for its stability and high absorptance and high emissivity. Because of the gray spectral response, it served as a basis to compare the solar simulation intensity used in tests with the sunlight. ARF-2, a zinc oxide potassium silicate paint, also known as Z-93, was chosen as typical of the white paints having low absorptance and high emissivity. It had been



Surface finish	Initial reflective properties, α/ϵ
1. Polished aluminum with ARF-2 control stripe	5.0
2. Aluminum silicone paint	0.89
3. Cat-a-lac black paint	1.04
4. ARF-2 white paint	0.28

FIGURE 10.—Solar absorptivity standards experiment. Temperature measurement accuracy was within 0.2°F .

found to be very resistant to ultraviolet exposure in laboratory testing, and was not expected to degrade by yellowing during the mission. Two of the samples, ARF-2 and polished aluminum, were modified with black control stripes to make the sample temperature ranges compatible with instrument design.

The actual and predicted temperatures are compared for the duration of

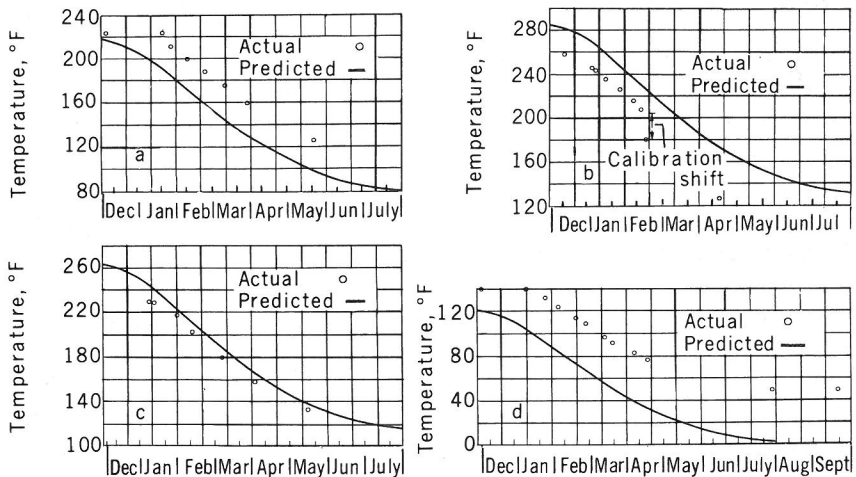


FIGURE 11.—Results of solar absorptivity experiment. The predicted data were based on laboratory surface property measurements and do not include losses.

(a) Polished aluminum with ARF-2 control stripe (channel 433). (b) Cat-a-lac black paint (channel 432). (c) Aluminum silicone paint (channel 413). (d) ARF-2 white paint with Cat-a-lac black control stripe (channel 412).

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the flight in figure 11. The predicted temperatures shown did not allow for any degradation of the surfaces due to ultraviolet radiation or other factors.

The differences between the actual and predicted values are attributed to (1) changing surface characteristics due to space-environment effects, (2) uncertainties in the exact value of the solar constant, (3) uncertainties in laboratory measurements, and (4) instrument inaccuracies. Instrument calibrations indicated the measurements to be correct to within 0.2° F over a 200° F range.

The Cat-a-lac black paint showed very little degradation. The ARF-2 white sample showed continuing degradation. The rate of degradation was about 10 times as great as that found in the laboratory under the ultraviolet testing which led to the selection of the sample. Laboratory tests made to determine possible effects of ultraviolet radiation indicated extreme difficulty in making two identical batches of paint and in predicting effects of the environment on the paint degradation. The aluminum silicone sample showed some degradation in time; however, the measured temperatures were very close to those predicted. The polished aluminum sample exhibited an appreciable change shortly after launch. This might be explained by outgas cleaning of the sample in space.

The actual comparison of these data obtained in interplanetary flight with those obtained in solar simulators will enhance the ability of engineers to predict future spacecraft temperatures and to design control surfaces capable of long-term operations in space (ref. 12).

SELECTING A SCIENTIFICALLY BALANCED PAYLOAD

Sixteen scientific experiments were considered before selecting eight instruments for the Mariner mission. The scientists who had proposed the 16 experiments were brought together for discussions with engineers responsible for integrating the experiments and the spacecraft. After each experiment had been considered, along with the constraints necessary from the spacecraft standpoint, a set of nine experiments was chosen which were complementary in nature and which would provide meaningful information throughout the journey from Earth to Mars, as well as in the vicinity of Earth and Mars (ref. 5). The occultation experiment did not require an instrument since it was to make use of the radio-frequency telemetry signal.

The hazards of a trip to Mars were unknown prior to the launch of Mariner IV; it was therefore considered essential that exploratory measurements be made to determine the nature of the interplanetary environment, particularly those aspects of the environment which might affect future missions. The particles and fields in space and in the vicinity of Mars were thought to be particularly significant for study, as was the cosmic-dust distribution outward to Mars. The possibility of radiation belts near Mars had been hypothesized, and the proximity of the planet to the asteroid belt

made it seem possible that particulate matter might exist in greater quantity near the orbit of Mars than near Earth. Since the Sun is the dominating factor on both the interplanetary environment and the planets themselves, measurements of its effects throughout the mission were considered especially important. All experiments chosen for interplanetary measurement were also capable of providing data on the Mars environment. Experiments which focused directly on Mars itself were the television camera, the ultraviolet photometer, and the radio-frequency occultation experiment. In summary, the combination of experiments selected for the initial mission to Mars made exploratory measurements of solar effects, the interplanetary and trapped radiation environment, the particulate matter in space, the magnetic fields of Earth, interplanetary space, and Mars, the nature of the Martian atmosphere, and the Martian surface features.

Of the nine scientific experiments so carefully chosen, only eight were actually conducted on Mariner IV. Late in final testing of the completed spacecraft, the ultraviolet photometer began arcing after 30 hours in a hard vacuum, with instabilities that represented a danger to the spacecraft's electronics. The time that would have been needed for redesign and retesting was not available if Mariner IV was to meet its launch schedule, and so the instrument had to be removed from the spacecraft.

The experiments conducted with Mariner IV and the investigators responsible for each are presented in the following table:

<i>Helium magnetometer: planetary and interplanetary magnetic fields</i>	E. J. SMITH of Jet Propulsion Laboratory, P. J. COLEMAN, JR., of University of California, Los Angeles, L. DAVIS, JR., of California Institute of Technology, and D. E. JONES of Brigham Young University and Jet Propulsion Laboratory
<i>Trapped-radiation detector: low energy solar charged particles and planetary radiation belts</i>	J. A. VAN ALLEN, L. A. FRANK, and S. M. KRIMIJIS, all of State University of Iowa
<i>Cosmic-dust detector: micrometeorite count and momentum</i>	W. M. ALEXANDER, O. E. BERG, C. W. MCCracken, and L. SECRETAN, all of NASA Goddard Space Flight Center, and J. L. BOHN and O. P. FUCHS of Temple University
<i>Cosmic-ray telescope: high-energy charged particles</i>	J. A. SIMPSON and J. O'GALLAGHER of University of Chicago
<i>Solar-plasma probe: quantity rate and energy of positive ion wind</i>	H. L. BRIDGE and A. LAZARUS of Massachusetts Institute of Technology, and C. W. SNYDER of Jet Propulsion Laboratory

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<i>Ionization-chamber/particle-flux detector: corpuscular-radiation dose rate</i>	H. V. NEHER of California Institute of Technology and H. R. ANDERSON of Jet Propulsion Laboratory
<i>Television: 21 pictures of the Martian surface</i>	R. B. LEIGHTON, B. C. MURRY, and R. P. SHARP, all of California Institute of Technology, and R. K. SLOAN and R. D. ALLEN of Jet Propulsion Laboratory
<i>Occultation (no instrumentation): Martian atmosphere as deduced from its effect on spacecraft's signal during occultation by the planet</i>	A. J. KLIORE, D. L. CAIN, and G. S. LEVY, all of Jet Propulsion Laboratory, V. R. ESHLEMAN and G. FJELDBO of Stanford University, and F. DRAKE of Cornell University

These investigators are scientists well known for their work in the disciplines represented by their experiments. Many of them have been engaged in previous space flights, and all of the Mariner instruments, with the exception of the television system and the magnetometer, were evolved from models previously flown in space.

SCIENTIFIC HIGHLIGHTS

It would be impossible to treat in one paper all important results reported by investigators who participated in the experiments conducted with Mariner IV. In the summaries which follow, key findings are presented which the author feels highlight returns from the Mariner IV mission.

The Magnetometer

Mariner's helium vapor magnetometer was developed under the direction of E. J. Smith at the Jet Propulsion Laboratory. It provided a resolution of the telemetered magnetic data of 0.35 gamma per axis (1 gamma equals 10^{-5} gauss) and a dynamic range of ± 360 gammas along each of three axes. It was mounted high on the spacecraft low-gain antenna boom to minimize the effect of spacecraft fields. The instrument weighed 6.77 pounds and required 7.3 watts of power (refs. 4 and 13).

The magnetometer detected the Earth hydromagnetic bow shock at a Sun-Earth-probe angle of 110° and a geocentric distance of approximately 37 earth radii. A variability in the position of the bow shock was observed with approximately seven transversals between 36.6 and 38.6 earth radii (ref. 13). The power spectra of the magnetic-field variation in the transition region near the shock front were determined for fluctuations with periods from 25 seconds to 30 minutes, and an average total energy density of about $5 (\text{gamma})^2/\text{cm}^3$ (ref. 14). Pronounced oscillations with periods near 3

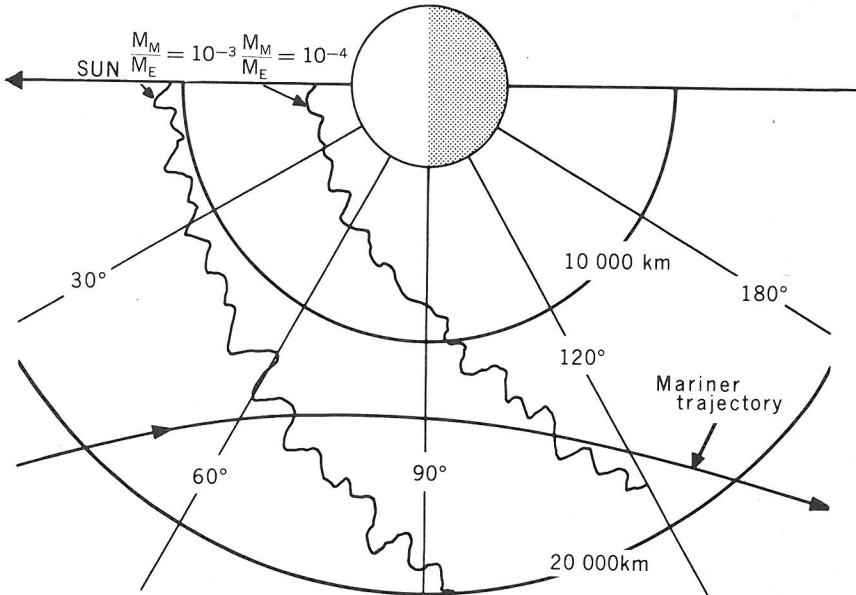


FIGURE 12.—Mars shock fronts—various magnetic fields (courtesy E. Smith).

minutes were detected, which appeared to be hydromagnetic waves associated with fluctuations in the position of the magnetopause.

The average magnitude and direction of the interplanetary field were consistent with earlier Mariner II and Explorer XVIII (IMP I) observations. There was a tendency, however, for the interplanetary field to exhibit a polarity pattern that corotated with the Sun. In general, the specific patterns during the Mariner IV observations were different from those observed earlier by Mariner II and IMP I. Mariner IV data also revealed an evolution in the polarity pattern from one solar rotation to another, including the occurrence of long time intervals where the pattern became difficult to recognize (ref. 15).

Figure 12 shows calculated shock front locations for Mars, assuming magnetic dipole moments of 10^{-3} and 10^{-4} times that of Earth. The Mariner trajectory should have clearly encountered a shock front having a ratio of magnetic dipole moment of Mars to that of the Earth (M_m/M_e) of 10^{-3} and possibly 10^{-4} if it had existed. The data in figure 13 were taken directly from the magnetometer telemetry readings. The only effect which might be interpreted as representing a hydromagnetic shock front occurred at an areocentric range of about 15 000 to 20 000 kilometers, slightly after the closest approach to the planet. Therefore, measurements (ref. 16) indicated that the magnetic dipole moment could be, at most, only 3×10^{-4} times as large that of Earth.

MARINER IV RESULTS

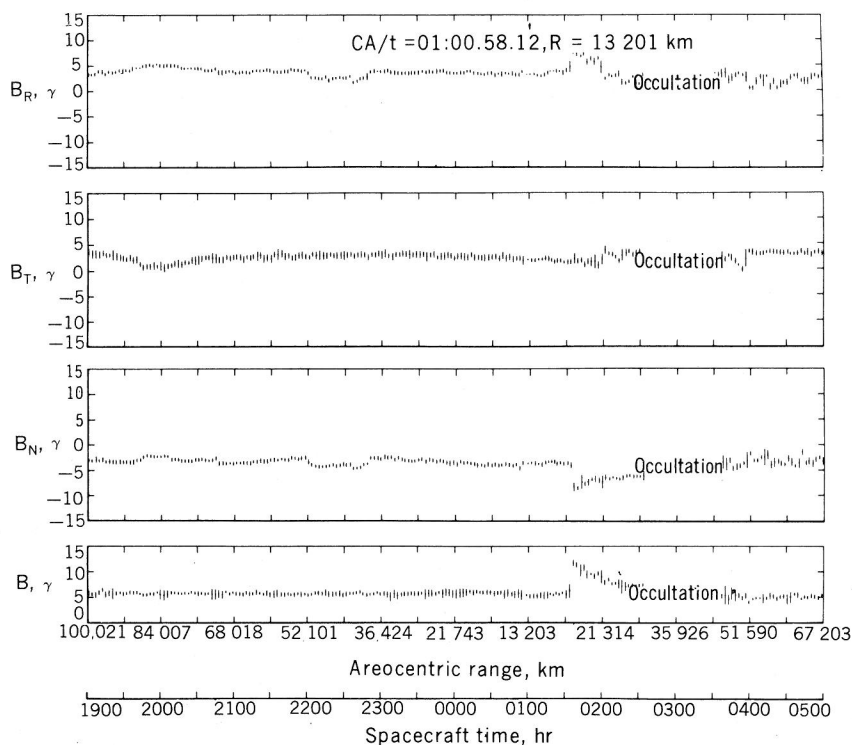


FIGURE 13.—Mariner IV—Mars encounter magnetometer data (courtesy E. Smith).

Trapped Radiation Detectors

The trapped radiation instrument was developed at the State University of Iowa, with James A. Van Allen as principal investigator (ref. 17). The instrument was designed to measure the electron and proton radiation belts around the Earth, similar formations around Mars if existent, and related phenomena in interplanetary space; it weighed 2.17 pounds and used 0.44 watt of power. Four detectors were flown with acceptance angles of 60° , three pointed 70° and one 135° away from the Sun. Electrons and protons were detected over the following ranges (ref. 18):

Detector	Electrons	Protons
A	≥ 45 keV	670 ± 30 keV
B	≥ 40 keV	$> 550 \pm 20$ keV
C	≥ 150 keV	3.1 MeV
D ₁	None	0.5 to 11.0 MeV
D ₂	None	0.88 to 4.0 MeV

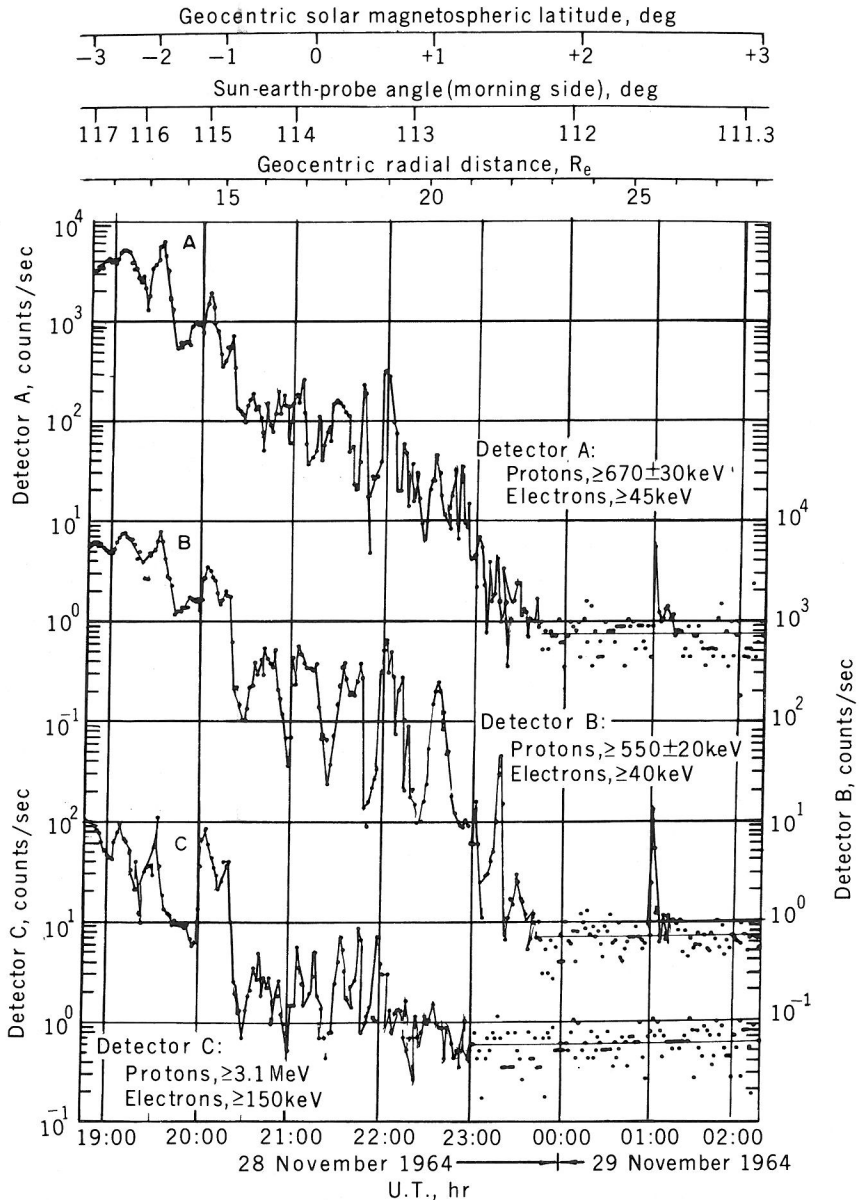


FIGURE 14.—Mariner IV trapped radiation near Earth (courtesy J. Van Allen).

Data taken near the Earth with electron detectors A, B, and C clearly show effects during traversal of the Earth's magnetosphere (fig. 14). These data provided a calibration of the capabilities of the system and a basis for the interpretation of observations obtained later during the Martian encounter.

MARINER IV RESULTS

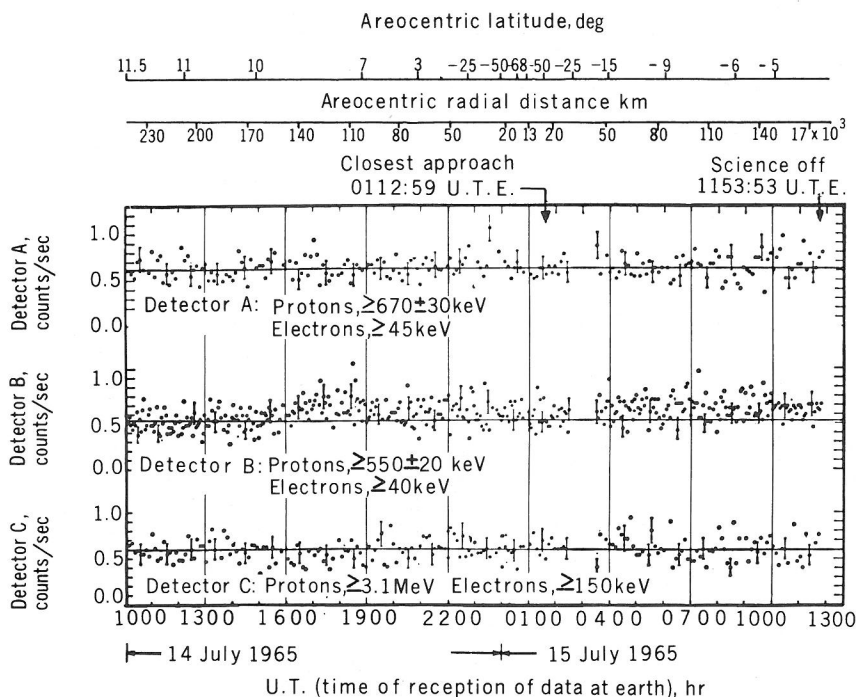


FIGURE 15.—*Mariner IV trapped radiation near Mars (courtesy J. Van Allen).*

The intensity of protons greater than or equal to 0.5 MeV, and less than or equal to 11 MeV, dropped to an undetectable level at a radial distance of 10.5 earth radii. Electrons with energy greater than 40 keV were detected continuously out to 23 earth radii, with an outlying intensity spike at 25.7 earth radii (ref. 18).

During the trip to Mars, Mariner IV passed during late January and early February 1965 through the presumed region of an extended magnetospheric tail of the Earth, at a geocentric distance of approximately 3300 earth radii. The counters, which had shown the presence of electrons greater than 40 keV out to 23 earth radii in the morning fringe of the magnetosphere during the early phase of the flight, failed to detect any effects of a magnetospheric tail during 7 days of flight within a geocentric angle between 1° and 5° from its presumed center line. Although a negative result, this is considered particularly significant (refs. 19 and 20).

Data obtained during the approach and encounter with Mars (see fig. 15) contrast sharply with those obtained in the vicinity of Earth just after launch. The same sensitive particle detectors, which were able to indicate the presence of electrons of energy less than 40 keV out to a radial distance of 165 000 kilometers in the morning fringe of the Earth's magnetosphere, failed to

detect any such electrons during the close encounter with Mars at the time when the minimum areocentric radial distance was 13 200 kilometers. This result indicates that M_m/M_e is surely less than 10^{-3} and probably less than 5×10^{-4} . Corresponding upper limits on the equatorial magnetic field at the surface of Mars are 200 and 100 gammas, respectively, as contrasted with a field at the Earth's surface of about 50 000 gammas. It appears possible on the basis of this finding that the solar wind interacts directly with the Martian atmosphere (ref. 18).

Cosmic Dust Detector

The cosmic dust detector was developed at the NASA Goddard Space Flight Center, under the leadership of W. M. Alexander. It consisted of an aluminum plate with an area of 350 square centimeters. Each surface of the plate was covered with a thin-film capacitor, and an acoustical transducer was bonded to the plate. This instrument was able to ascertain the number of hits and the momentum of each hit greater than 0.00006 dyne-second. The threshold sensitivity of the acoustical transducer was $6 \pm 0.7 \times 10^{-5}$ dyne-second and the dynamic range of the pulse height analyzer extended to 1.96×10^{-3} dyne-second. The instrumentation also contained a calibration device which performed a calibration approximately three times a day when the telemetry bit rate was high and approximately once a day when the bit rate was low. The detector weighed 2.10 pounds and required 0.23 watt of power (refs. 4 and 21).

Recorded impacts for 5-day intervals are shown throughout the flight mission (fig. 16). The major results from the measurements are:

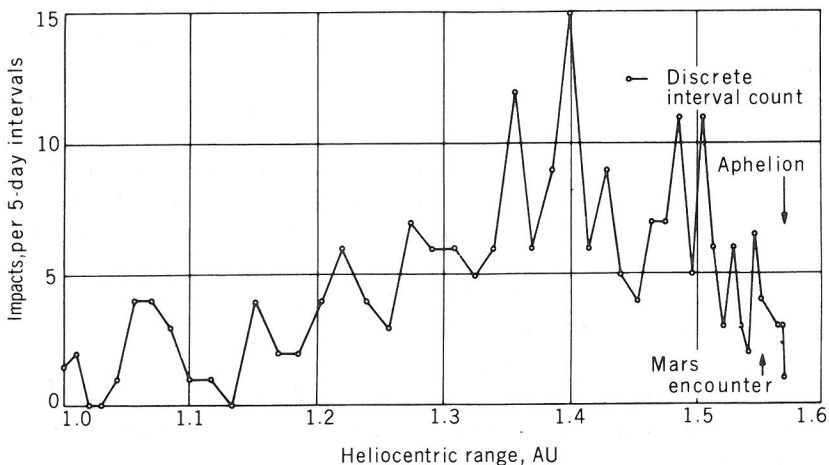


FIGURE 16.—*Mariner IV* cosmic dust impacts (courtesy W. Alexander).

MARINER IV RESULTS

- (1) An enhancement of the flux between the orbits of Earth and Mars
- (2) A change in accumulative flux mass distribution curve (flux varied as a function of $M^{-0.55}$ power (M is mass) near both planets and dropped to $M^{-0.9}$ power between the planets)
- (3) No statistically significant evidence of well-defined dust particle streams
- (4) No measurable enhancement of the flux in the vicinity of Mars
- (5) Near Earth, the flux measured by the Mariner IV experiment is consistent with the measurements from the Mariner II instrumentation.

The pattern between Earth and Mars was generally one of a regular increase going toward Mars with a falling off as the orbit of Mars was approached. This suggests that each planet sweeps a relatively dust-free path as it travels around the Sun, and that, over the region from Venus to Mars at least, the particles become fewer nearer the Sun. No well-defined dust streams were identified, although a few cometary-orbit streams were encountered (ref. 21).

Cosmic-Ray Telescope

Developed under the direction of Professor John A. Simpson, University of Chicago, the cosmic-ray telescope was designed to study both the interplanetary environment and that of Mars. The instrument was mounted on the shadowed side of the spacecraft during cruise flight, looking in the opposite direction to the Sun with a 40° field of view. It detected protons in three ranges from 0.8 to 190 MeV, and alpha particles in three ranges from 2 to far more than 320 MeV. The instrument weighed 2.58 pounds and required a power of 0.598 watt (refs. 4 and 22).

The instrument is known to have remained stable to within 1 percent of preflight calibration, allowing an accurate determination of the radial intensity gradient (ref. 22). As the energy ranges for this experiment were the same as those of similar experiments on Earth-orbiting satellites, an excellent spatial-time correlation of events is possible.

The instrument reported a complete absence of trapped electrons and protons at Mars, and it also substantiated the data of the magnetometer and the trapped radiation detectors in setting an upper limit on the Martian magnetic moment of 10^{-3} times that of Earth (ref. 23).

Perhaps the most significant findings of this experiment occurred during the interplanetary phase of the flight.

During the Mariner IV mission, one moderately large solar-proton event, and several much smaller events associated with solar activity (i.e., solar flares or 27-day recurring regions on the Sun), were observed by the cosmic-ray telescope. Almost all of these events, including the large event, were observed simultaneously by University of Chicago instruments on Earth-

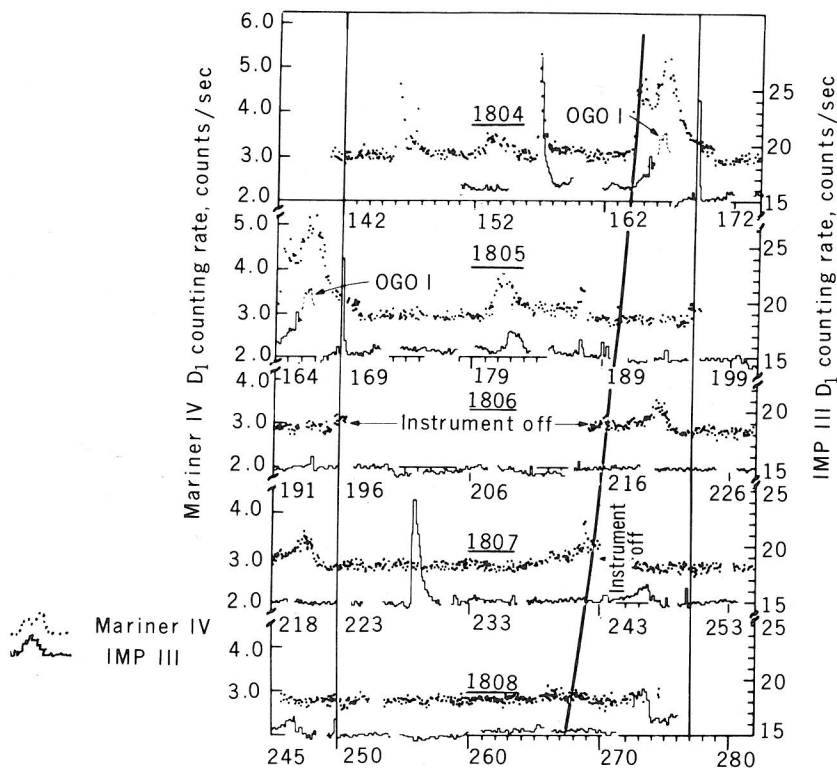


FIGURE 17.—Cosmic ray counting rates (courtesy J. Simpson).

orbiting satellites, especially Explorer XXVIII (IMP-III). The analysis of the time and spatial relations between these simultaneous observations yields several new conclusions that would not have been evident from measurements at a single point in interplanetary space (ref. 24).

The general properties of the spatial and temporal variations for events associated with two classes of solar-related events (i.e., solar flares and 27-day recurring regions) may be understood from a comparison of the counting rates of the front detector (D_1) on the Mariner IV and IMP-III instruments from May 20 to October 1, 1965, during which time a number of very small increases in particle intensity were observed. The continuous time-intensity profile for these observations is shown in figure 17 for successive solar rotations 1804 to 1808. The counting-rate channel shown is for protons of energy $\gtrsim 1$ MeV and electrons $\gtrsim 200$ keV on both instruments (refs. 25 and 26).

The trajectory of Mariner IV was such that for most of the mission, the probe fell steadily behind the Earth as they both moved around the Sun. Thus, corotating regions arrived at Mariner IV before they arrived at Earth for

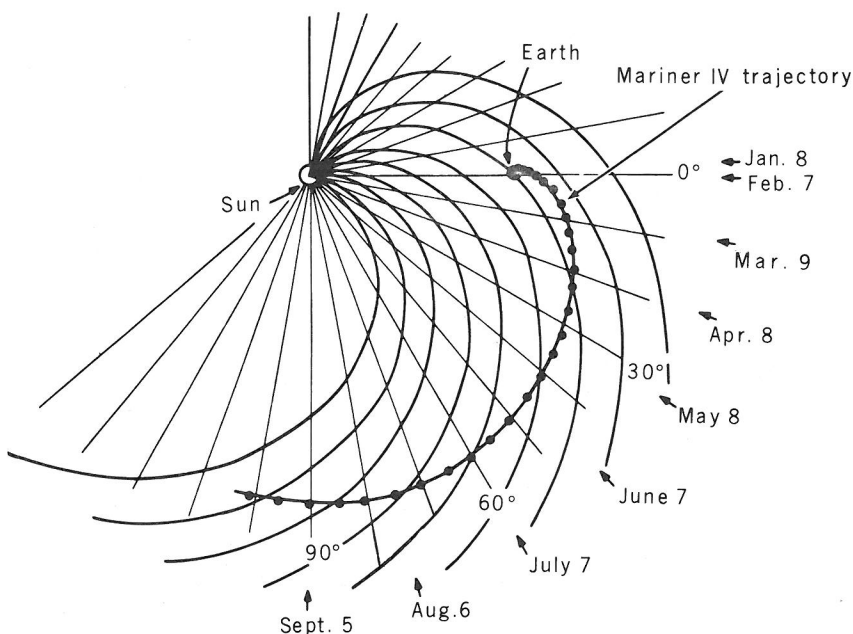


FIGURE 18.—Idealized interplanetary magnetic field configuration (courtesy J. Simpson).

most of the last half of the mission, as shown in figure 18. By relating the observations in figure 17 to the heliographic longitude of the pertinent solar activity and to the relative radial and angular separation of the two observations, the following general qualitative conclusions are evident:

First, it is apparent that the particles propagate by anisotropic diffusion; that is, they are strongly directed along, rather than across, the spiral interplanetary magnetic fields.

Second, the particles are sometimes injected, stored, and transported for periods in existing corotating magnetic-field regions. These properties are not plainly evident from measurements at a single position in space where observations have usually been brought in agreement with one of the many isotropic diffusion models.

Third, there is also evidence of at least one series of so-called "27-day" regions, recurring for at least three solar rotations, of a type similar to those observed earlier on the IMP-I satellite (ref. 27).

The two major conclusions of the study of these small events, namely, (1) strongly anisotropic diffusion along spiral magnetic lines of force, and (2) corotation of stored particles in limited angular regions, serve to explain quantitatively the differences between the observations made by IMP-III and Mariner IV of the larger flare of February 5, 1965.

Solar-Plasma Probe

The solar-plasma probe was developed at the Massachusetts Institute of Technology under the direction of Professor Herbert Bridge. It was designed to measure the charged particles making up the solar wind, a hot, ionized gas streaming out at hypersonic velocity from the corona of the Sun. Positive ions (protons and alpha particles) were detected in 32 energy bands, ranging from 45 to 9400 eV. The instrument was mounted on the spacecraft facing toward the Sun, with a conical field of view of 60° ; it weighed 6.41 pounds and used 2.65 watts of power.

The failure of a high-voltage bleeder resistor in the instrument power supply circuitry, 8 days after launch, made it impossible to use the data obtained at the high bit rate during most of December 1964. When the low bit rate commenced in January 1965, it was again possible to obtain meaningful measurements from the instrument.

Plasma data obtained during the planetary encounter support the results obtained from the magnetometer and the trapped radiation detectors. There is no clear indication that any magnetic fields from Mars were influencing the plasma flow.

Figure 19 shows 3-hour averages of proton flux, density, and bulk velocity. This data sample shows a general feature noticed throughout the flight—the tendency for density and velocity changes to be anticorrelated. The same effect has been reported by Neugebauer and Snyder (ref. 28), using data from the plasma probe carried on Mariner II. According to A. Lazarus of

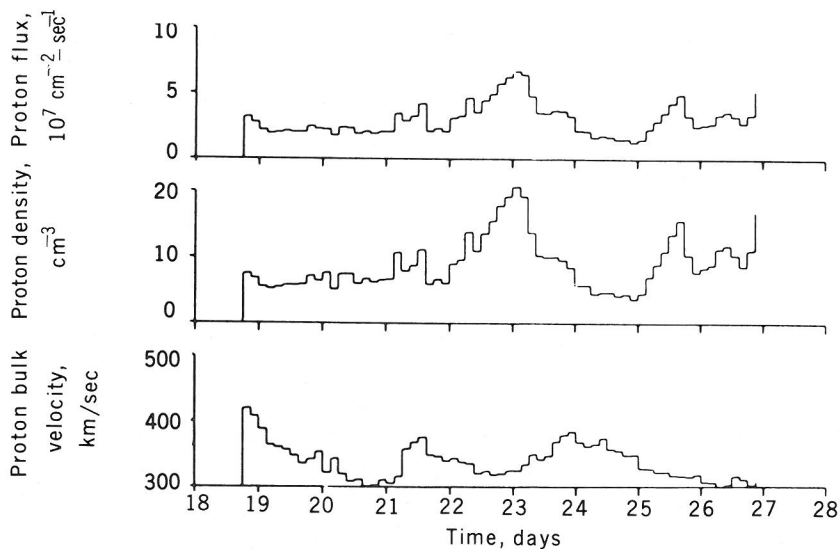


FIGURE 19.—Mariner IV plasma probe data (3-hour averages) from January 18 to 26, 1965 (courtesy H. Bridge).

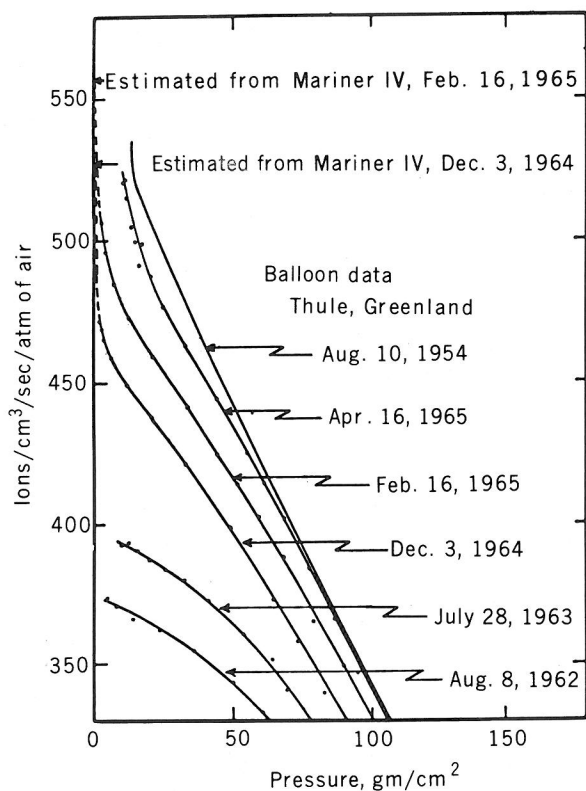


FIGURE 20.—
Ion count correlation
between balloon data
and that of Mariner IV
(courtesy H. Neher).

the Massachusetts Institute of Technology, longer periods of data show a repetitive structure in plasma flux, density, and velocity.

In addition, Lazarus indicated that during the first 3 months of 1965, the solar wind bulk speed varied from 275 km/sec to 530 km/sec. At the time of the Mars encounter, the bulk speed was approximately 330 km/sec and the density was about 0.8 proton/cm³.

Ionization Chamber

The ionization chamber and Geiger-Müller tube measured the ionization caused by charged particles and the number of particles in the range above ½ MeV for electrons, and 10 MeV for protons. Dr. H. V. Neher of the California Institute of Technology was the principal investigator for this experiment. The instrument produced considerable information on cosmic rays during a period of minimum solar activity; it weighed 2.90 pounds and required a power of 0.460 watt (ref. 4). The Geiger tube was damaged, apparently by the solar flare radiation of February 5, 1965, and the data from it became unusable after February 10. The failure of the Geiger-Müller

tube affected the instrument power supply, so that the companion ionization chamber ceased operating altogether on March 17, 1965.

The ionization chamber experiment showed that the intensity of radiation within the magnetosphere, near the equatorial plane, varies smoothly with distance out to 8.2 earth radii, in the direction of 0400 local time, which presumably marks the limit of simple trapping. From 8.2 to 15.3 earth radii, the intensity varied complexly, and at greater distances from Earth, only interplanetary levels were observed.

Following a solar flare on February 5, 1965, the ion rate increased to 200 times the galactic cosmic ray rate, and the flux increased to about 80 times. The general variation of intensity with time after the flare can be described by diffusion of particles in the interplanetary medium. In addition, there were later fluctuations which are ascribed to the subsequent ejection of particles from the Sun, or to modulation of particles in the interplanetary medium.

Since the same detectors were flown on both the Mariner II and Mariner IV missions, it is possible to compare the data collected near Venus in 1962 with that measured near Mars in 1964-1965. According to Dr. H. R. Anderson, the values of the omnidirectional flux and ion rate both increased about 40 percent during this time (from 2.86 to 4.0 to 4.3 particles/cm²/sec, and from 665 to 930 to 1010 ion pairs/cm³/sec/atm of air, respectively). The variation in cosmic-ray flux with time, measured by the two Mariner flights, correlates very well with similar observations made with high altitude balloons, during the same 2-year period, as shown in figure 20 (ref. 29). The somewhat lower increase (24 percent) in flux observed by the high altitude

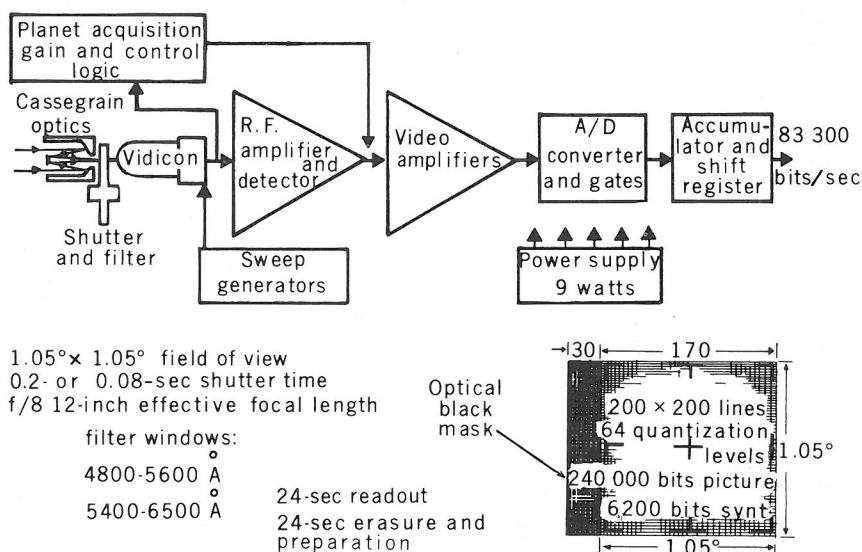


FIGURE 21.—Simplified schematic of Mariner IV television.

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measurements near Thule, Greenland, may be explained by assuming a large increase of low-energy particles which were registered by the Mariner instruments, but were unable to penetrate the residual atmosphere above the balloon-borne instruments.

It also appears that cosmic-ray intensity was greater during 1954–1955 than during 1964–1965, both of which were periods of solar minimum. This is presumably due to lower solar activity during the 1954 minimum, with the consequent production of more low-energy particles (ref. 29).

Television

The Mariner television system was built around the vidicon, a TV image tube whose compact dimensions and modest power requirements make it suitable for spacecraft use (fig. 21). The television system was designed and built at the Jet Propulsion Laboratory. Professor Robert Leighton of the California Institute of Technology was principal investigator. The science-control subsystems of the Mariner shuttered the camera optics every 48 seconds, placing red and green filters alternately before the lens. A telescope with a 12-inch focal length and 1° field of view brought the image, about 0.22 inch square, to the vidicon faceplate. Scanning the image in 200 lines (of

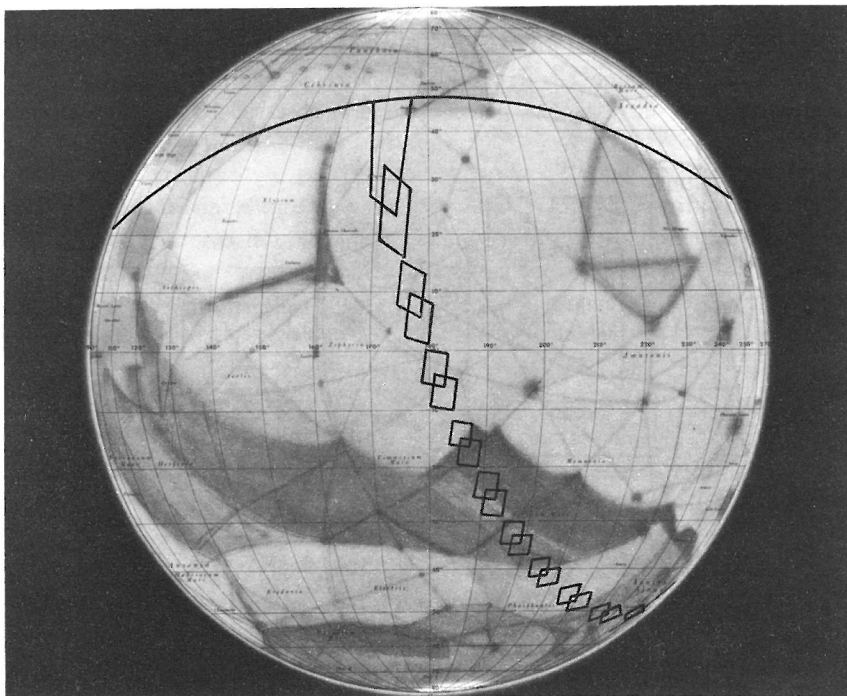
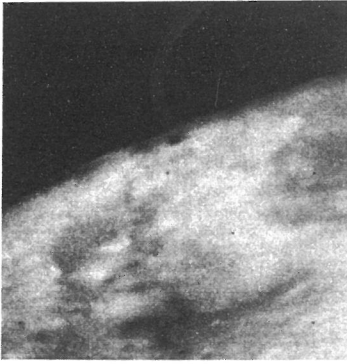
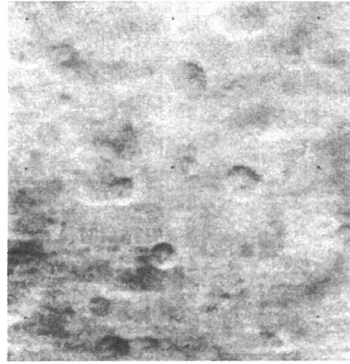


FIGURE 22.—*Television coverage of Martian surface.*

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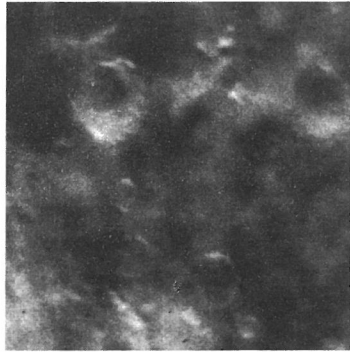
Number 1. Altitude: 16 500 km; area: Phlegra, 35° N. latitude × 172° E. longitude; scale: 660 km along the limb × 1290 km.



Number 9. Altitude: 13 000 km; area: Mare Sirenum, 23° S. latitude × 191° E. longitude; scale: 270 km E-W × 260 km N-S (north at top).



Number 11. Altitude: 12 500 km; area: Atlantis, 31° S. latitude × 197° E. longitude; scale: 270 km E-W × 240 km N-S (north at top).



Number 14. Altitude: 12 200 km; area: Phaethontis, 41° S. latitude × 208 E. longitude; scale: 240 km E-W × 230 km N-S (north at top).

FIGURE 23.—*Photographs of Martian surface.*

200 dots or picture elements each), the TV camera produced a digital signal of 240 000 bits per picture. This was recorded on a two track 1/4-inch magnetic tape loop 330 feet long, capable of recording slightly more than 21 pictures. The tape ran over the recording head at about 13 in/sec, and was stopped between pictures to save tape. Only two out of every three pictures taken were recorded on the tape, resulting in a chain of pairs of overlapping, alternately filtered pictures extending across the disk of Mars (fig. 22). The television subsystem weighed 11.28 pounds and required 8 watts of power during operation (refs. 4, 6, 7, and 30).

Four representative pictures from the 21 (and a fraction) pictures returned by Mariner are shown in figure 23. These pictures have been computer-

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enhanced at the Jet Propulsion Laboratory by a point transformation involving linear interpolation where fractional picture element displacements occurred. The first picture captured the limb of the planet, and the last picture was taken near the southern polar region at the terminator. The most striking characteristic of the photographs is the densely packed, lunar style, impact craters on the surface. Nearly 100 craters appear in the Mariner IV pictures, which cover less than 1 percent of the Martian surface. If these areas are representative, Mars might be covered with 10 000 craters in the 3- to 75-mile-diameter class. Slopes measured so far range only up to 10° . Crater rims rise perhaps hundreds of feet above the surrounding terrain, and their interiors are depressed in the thousands of feet. One large elevation change on picture 11 has been estimated at 13 000 feet.

Picture 1 showed unexpectedly high light levels above the limb of the planet. Other pictures also give some evidence of fogging, as if the atmosphere were both brighter and more extended than had been anticipated. Initially it was assumed that this had been caused by an imperfection in the optical or TV system, but it has not proved possible to duplicate this either on calibration pictures taken several weeks after encounter or by the introduction of deliberate defects in identical equipment. Accordingly, the experimenters now tentatively conclude that the cause of the fogging is actually on Mars. Some evidence suggests that the Martian atmosphere may contain tiny crystals of frozen carbon dioxide at great height. The cloud shown in picture 1, if it is a cloud, extends as much as 100 kilometers above the surface.

A plot of crater densities, shown in figure 24, compares craters seen on Mariner IV pictures with data obtained from astronomical observations of

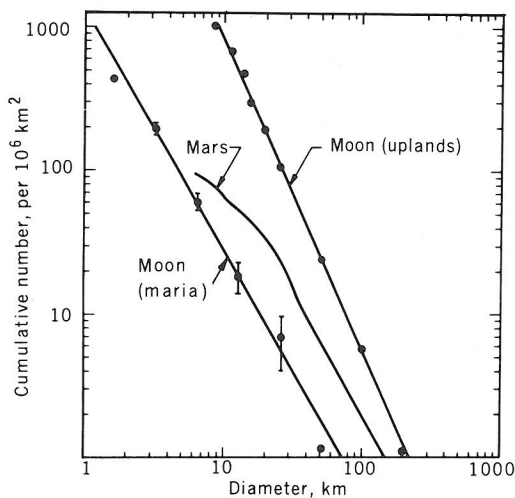


FIGURE 24.—
Mars crater densities
(courtesy R. Leighton)

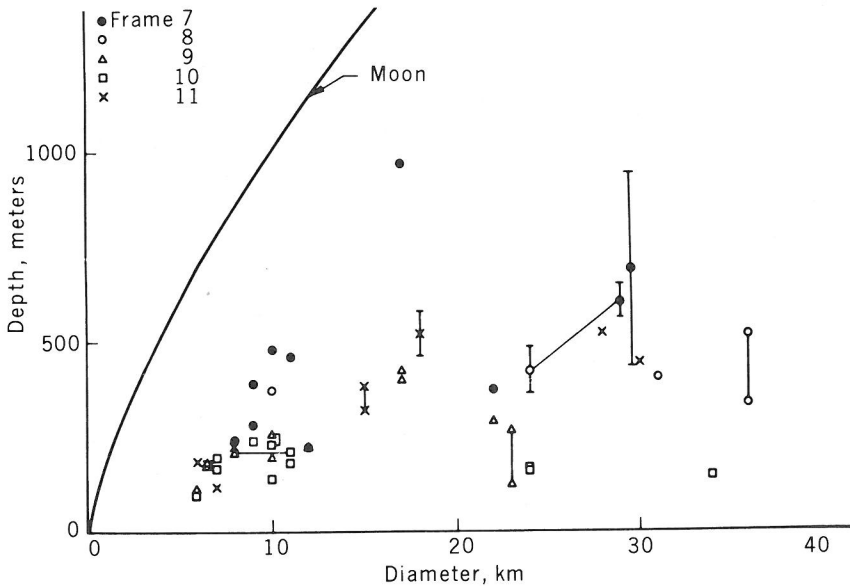


FIGURE 25.—Mars crater depths (courtesy R. Leighton).

the Moon. It is interesting to note that, although the Mars data sample is relatively small, it is bracketed by the number of craters on the maria and uplands of the Moon. Another plot (fig. 25) compares the depth and diameters of Martian craters with those of the Moon. The depths were estimated by plotting the light values of successive picture elements on a line cutting across the diameter of a crater (refs. 11 and 30).

A number of craters near the evening terminator and the southern pole appeared to be frosted. A whitish substance shows on both the sunlit and shaded sides of some craters as indicated in picture 14 (fig. 23). The nature of this frost is, of course, unknown. No clear evidence of the famous Martian canals is apparent in the Mariner pictures, although Clyde Tombaugh has found dark markings and lineaments which correspond with faintly visible features previously mapped as canals and oases by telescopic observations (ref. 31).

The unearthly appearance of Mars as seen from the spacecraft has had a major impact on our concept of Martian history. The topography of Mars is evidently very old and appears to have changed very little over the years. Impact craters of Martian and lunar proportions may have existed on Earth at one time, but the processes of growth and weathering, of mountain building and glacial canyon carving, have long since destroyed most such features. Mars in its Moon-like appearance seemingly has not been subject to the erosional or tectonic processes that so markedly changed the face of Earth.

Occultation Experiment

By planning the trajectory of Mariner IV so that it passed behind Mars, the radio signal from the spacecraft passed through the Martian atmosphere until it was occulted by the planet, and reappeared through the atmosphere later. This allowed study of the changes in frequency, phase, and amplitude of the Mariner IV radio signal as it passed through the atmosphere and ionosphere of Mars immediately before the occultation and after the reappearance of the spacecraft. Preliminary analysis of these effects has yielded estimates of the refractivity and density of the atmosphere near the surface, the scale height of the atmosphere, and the electron density profile of the Martian ionosphere.

This experiment was especially attractive because it did not require any special equipment in the spacecraft. It utilized the radio-frequency signal necessary for tracking and telemetry for the routine spacecraft operations. The principal investigator for this experiment was Dr. A. Kliore of the Jet Propulsion Laboratory.

About 1 hour 15 minutes after the closest approach of the Mariner to Mars, the radio signal began to graze Mars' ionosphere. For about 2 minutes, the 2300 megacycle signal was bent and diffused by the atmosphere, and then it vanished at 02:31:12 G.m.t. Nearly an hour later, at 03:25:06 G.m.t., the signal reappeared and tracking began again. A plot of the actual signal phase differences measured during the time of entering occultation is presented as figure 26.

Mars occulted the spacecraft with its sunlit side between Electrus and Maria Cronium at 55° South latitude, 177° East longitude. The signal emerged

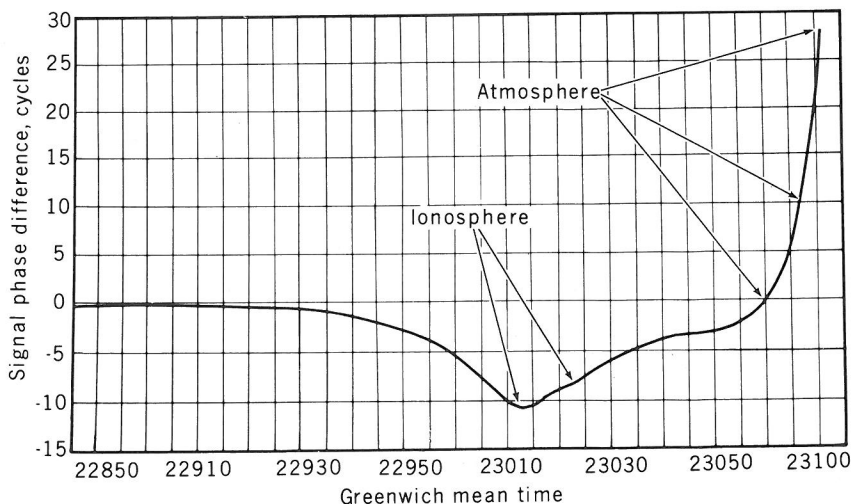


FIGURE 26.—Signal phase difference during occultation (courtesy A. Kliore).

above Maria Acidalum on the night side at 60° North latitude, 44° West longitude just before sunrise. The altitude above Mars at the time Mariner entered the occultation zone was 22 433 kilometers, and when it exited, it was at an altitude of 35 916 kilometers.

The maximum electron density encountered by the beam was 90 000 electrons/cm³ at an altitude of about 100 to 125 kilometers. From this the density at the subsolar point was calculated to be 150 000 electrons/cm³. Some indication of a second ionized layer below the denser one was observed. The ionosphere on the night side of Mars was so tenuous as to be undetectable when Mariner exited from occultation.

The atmospheric pressure at the surface was estimated at 4 to 7 millibars (about $\frac{1}{2}$ to 1 percent of Earth's surface pressure), depending on the argon/nitrogen/carbon dioxide portions assumed for the composition.

A summary of the findings from the occultation experiment showing the effects of varying atmospheric compositions (refs. 32 to 34) is presented in table II.

TABLE II.—*Summary of Occultation Experiment*

[From ref. 32]

Atmosphere	
Surface refractivity	3.6 ± 0.2 N units
Scale height	8 to 10 km
Surface number density:	
100% CO ₂	$1.9 \pm 0.1 \times 10^{17}$ mol/cm ³
Up to 20% A or N ₂ , or a mixture	$2.1 \pm 0.2 \times 10^{17}$ mol/cm ³
50% A	$2.5 \pm 0.15 \times 10^{17}$ mol/cm ³
Surface mass density:	
100 CO ₂	$1.43 \pm 0.1 \times 10^{-5}$ g/cm ³
Up to 20% A or N ₂ , or a mixture	$1.5 \pm 0.15 \times 10^{-5}$ g/cm ³
50% A	$1.75 \pm 0.10 \times 10^{-5}$ g/cm ³
Temperature:	
100% CO ₂	$180 \pm 20^\circ$ K
Up to 20% A or N ₂ , or a mixture	$175 \pm 25^\circ$ K
50% A	$170 \pm 20^\circ$ K
Surface pressure:	
100% CO ₂	4.1 to 5.7 mb
Up to 20% A or N ₂ , or a mixture	4.1 to 6.2 mb
50% A	5.0 to 7.0 mb
Ionosphere	
Maximum electron density ($\chi = 70^\circ$)	$9 \pm 1.0 \times 10^4$ el/cm ³
Altitude of maximum	120 to 125 km
Electron scale height above maximum	20 to 25 km
Temperature	$< 200^\circ$ K at 120 to 200 km

Astrodynamical Constants

Although the determination of astrodynamical constants was not treated as a scientific experiment on the Mariner mission, George Null and his associates at the Jet Propulsion Laboratory (ref. 35) made use of the extremely high accuracy of the two-way Doppler tracking of the Mariner spacecraft to determine the following two classes of results which are of scientific consequence: (1) a reconfirmation of certain of the astrodynamical constants obtained earlier from tracking deep-space probes and Venus radar bounce measurements, and (2) a dramatic improvement in the knowledge of the gravitational constant of Mars. This later improvement was possible because Mariner IV provided range-rate tracking of very high quality (range-rate uncertainty of approximately 0.06 cm/sec) during the encounter period when the Mariner IV trajectory was strongly perturbed by the Mars gravitational field. Some of the important results determined from the Mariner tracking data are as follows:

(1) A new gravitational constant for Mars (GM_m) of $42\,828 \pm 0.8 \text{ km}^3/\text{sec}^2$ has been determined. The gravitational constant of Mars is known only to three significant digits, and the mass of Mars (M_m) is also known only to three significant digits. Only the product GM_m is known to high accuracy. Since the gravitational constants of the Sun (GM_s) and Earth (GM_e) are known to better than one part in 10^6 it is possible to represent ratios of GM_s/GM_m with the same accuracy as GM_m . This ratio is the form in which such solutions are usually expressed by astronomers, and in this form

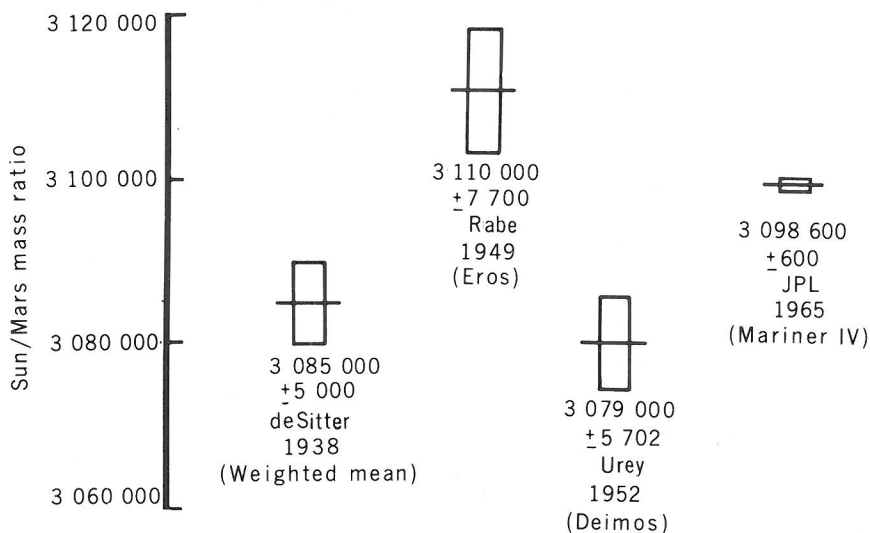


FIGURE 27.—Mass of Mars determinations showing probable errors (courtesy G. Null).

$GM_s/GM_m = 3\,098\,600 \pm 600$. This ratio is compared in figure 27 with the same ratio computed earlier by other scientists using different techniques.

(2) A provisional calculation has resulted in a new value for the astronomical unit (AU) based on a speed of light of 299 792.5 km/sec. The AU computed was $149\,597\,500 \pm 500$ kilometers. It is hoped that this value may be refined by further postflight analysis.

(3) An additional value obtained from Mariner data is the gravitational constant for the Moon (GM_l). The value of GM_l obtained is 4907.72 ± 0.1 km³/sec² which is consistent with results obtained on earlier Ranger and Mariner flights. The strength of the GM_l solution for a planetary probe comes from the motion of the Earth about the Earth-Moon barycenter.

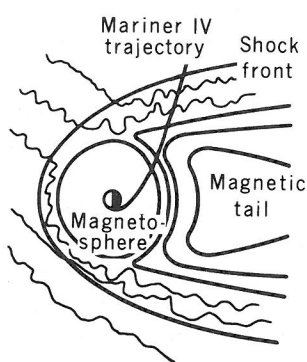
SUMMARY OF SCIENTIFIC FINDINGS

In the course of its journey, Mariner IV made 23 million scientific measurements (ref. 4). Its trajectory departing Earth and on arrival at Mars, along with an outline of the scientific findings reviewed in this report, are included in figures 28 and 29.

During its first 2 days in space, Mariner IV passed through the region of space influenced by the Earth, measuring with high precision the Van Allen belts, the attenuating magnetic field which holds them together, and the interface between solar plasma and geomagnetic fields. The geomagnetic shock front and transition region were pierced and measured in turn, leaving their traces on the data of the magnetometer, the plasma probe, trapped radiation detector, ionization chamber, and cosmic-ray telescope. About 2 months later, Mariner again passed through what was expected to be a zone influenced by Earth, when at a range of about $12\frac{1}{2}$ million miles, it came close to opposition—directly behind the Earth as seen from the Sun. Any magnetic plasma disturbance there corresponding to the Earth's wake was too faint for Mariner to detect. Through the journey to Mars, Mariner IV continued to measure the rise and fall of solar activity, and recorded about 200 micrometeorite impacts on a small sampling instrument. Although it made its journey during the period of the Quiet Sun; it detected a total of 12 to 20 solar-flare events, 6 of which were identified as being class II events. A number of these flares were observed optically from Earth as well as by the instruments carried on Earth-orbiting satellites. Solar winds varied widely during the flight, and magnetic fields fluctuated concurrently.

As it flew by Mars, Mariner IV conclusively proved that Mars has a very small magnetic dipole moment compared with that of Earth, if it has a moment at all. Measurements clearly showed that its moment is less than a thousandth that of Earth. This measurement was supported by the fact that no radiation belts were observed in the vicinity of Mars. Measurements of cosmic dust through the flight indicated no concentration of solid matter in the

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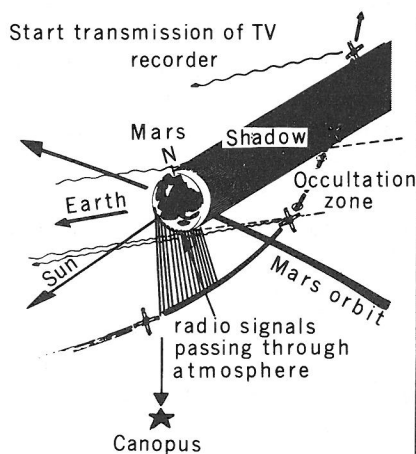


- Radial survey of Earth's radiation belts
- Earth's magnetosphere detected at 135 to 160 000 km
- Plasma shock observed at 238 to 257 000 km
- Twelve to twenty solar flare events measured
- Cosmic dust intensity increased between Earth and Mars
- Anisotropy of solar wind determined
- No geomagnetic wake seen at 20 million km
- Solar wind velocities measured — 275 to 600 km/ sec
- Interplanetary magnetic fields measured — average 5γ — maximum fluctuation $\pm 25 \gamma$

FIGURE 28.—Interplanetary scientific findings from Mariner IV.

vicinity of Mars. In fact, measurements seem to indicate that Mars has swept out its portion of the solar system and reduced the quantity of matter in this region.

Data on Mars itself included the surprising revelation that its atmosphere is extremely thin compared with that on Earth, with surface pressure measured between $\frac{1}{2}$ and 1 percent of that of Earth. It was also significant that the daytime ionosphere of Mars is approximately equivalent of that on Earth at night, with a critical frequency about 30 percent that of Earth. The discovery that the surface of Mars is characterized by crater-like features similar to Earth's Moon was a largely unexpected observation. It seems to indicate that the surface may be extremely old and preserved without the influence of erosive or tectonic events that occur on Earth. The close flyby of the Mariner and accurate tracking of the spacecraft on its trajectory allowed improve-



- Magnetic moment $< 0.1\%$ of Earth's
- No radiation belts observed
- No dust concentration near Mars
- Atmosphere surface pressure about $\frac{1}{2}\%$ to 1% of Earth's
- Ionosphere — critical frequency about 30% of Earth's
- Surface features — like the Earth's Moon
- Sun/Mars mass ratio — $3\,098\,600 \pm 600$

FIGURE 29.—Scientific findings at encounter from Mariner IV.

MARINER IV RESULTS

ments in the calculation of Mars' mass, and a new mass ratio with significantly improved accuracy was obtained.

From a viewpoint of 10 months past this historic encounter, it is clear that Mariner IV has provided much new information on the interplanetary medium, the environment of Mars, the atmosphere and surface features of this planet, and the design characteristics of efficient space probes. Detailed study will, in certain cases, supply more refined measurements than those presented here. Indeed, the data from Mariner IV will have value for years to come as they are supplemented and extended by the sensors aboard spacecraft as yet unlaunched.

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